Crop Raiding by Wildlife due to Landscape Modifications: Ecological Function Losses Caused by Forest Development on the Island of Yakushima, southern Japan

Naoki Agetsuma
Field Science Center for Northern Biosphere, Hokkaido University
Tomakomai Experimental Forest, Takaoka, Tomakomai 053-0035 Japan
E-mail: agetsuma@fsc.hokudai.ac.jp

Monotonous forest and deterioration of ecological functions

In primary industries, mass production requires intensive and monotonous land use, especially large-scale logging and commercial planting, such as seen in monocultures of coffee, palm, gum, and sugarcane, which are cultivated widely throughout tropical and subtropical regions (e.g., Nagata et al. 1994; Hartemink 2005). However, such monotonous land use has damaged the ecological functions and services that result from forest ecosystems (e.g., McNeely et al. 1990; Lugo 1997).

In Yakushima, located off the south coast of Japan, monotonous land use has developed mainly as large-scale logging of natural forests and replacement with coniferous trees, in accordance with policies of the Forest Agency that were formulated in 1958 and aimed at increasing wood production. However, forest development has disturbed animal and plant communities (e.g., Aiba unpub. data; Yumoto unpub. data) as well as ecological functions (e.g., Japan Institute of Land and Environmental Studies 1981). On the island of Yakushima, endemic subspecies of Japanese deer (*Cervus nippon yakushimae*) and monkeys (*Macaca fuscata yakui*) have experienced major habitat disturbance. In general, the food supply of herbivores fluctuate widely after logging and planting for about 20 years in Japan (e.g., Koizumi 1988; Sone et al. 1999; Hanya et al. 2005). Logging initially destroys plant production, but it quickly recovers with improved exposure to sunlight. However, it subsequently decreases rapidly to minimum levels, concomitant with growth of trees (Fig. 1). On Yakushima, the extensive forest transformations of the 1960s and 1970s have preceded intensive crop damage by these species in the 1980s and 1990s. Thus, crop raiding by mammals occur after major fluctuations in their habitat caused by monotonous plantations. This paper reviews the processes and factors of agricultural crop raiding by these mammals in relation to forest development on Yakushima, with reference to cases from other locations in Japan.

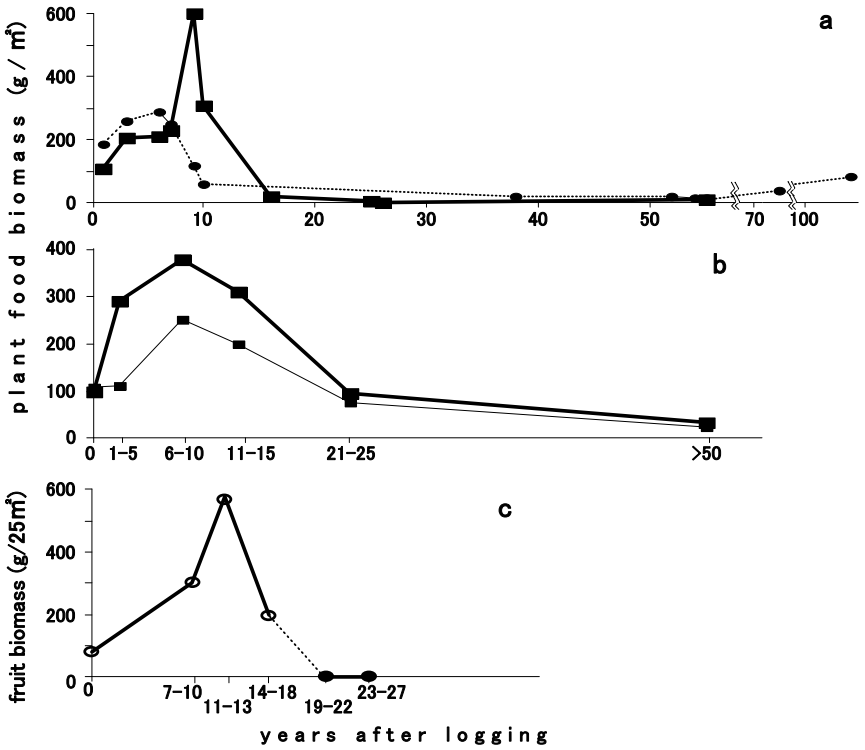

Fig. 1. Food plant biomass (g dry weight/m^2) after clear-cut logging of broad-leaved forests. (a) Food plant biomass for Japanese sika deer under cedar plantations (solid line) and secondary broad-leaved forests (broken line) (modified from Takatsuki 1992). (b) Food plant biomass (g dry weight/m^2) for Japanese serow under conifer plantations in November (solid line) and August (thin line) (drawn from Sone et al. 1999). (c) Fruit biomass (g/25 m^2), as food for Japanese monkey, in primary and secondary broad-leaved forests (solid circles) and cedar plantations (open circles) (modified from Hanya et al. 2005).

Forest development

Yakushima is a circular, mountainous island (ca. 500 km^2) located in southern Japan (30°N, 130°E). Approximately 14,000 inhabitants live in about 20 villages located less than 100 m above sea level (a.s.l.); most other areas are afforested with about 80% being National Forest property. Natural forests, consisting mainly of evergreen broad-leaved trees, occur from 0 to 800 m a.s.l.; between 800 and 1800 m, the forests consist of both broad-leaved and coniferous trees. In addition, many natural Japanese cedars occur, especially over 1200 m a.s.l. (Tagawa 1994). Annual precipitation at lower altitudes is 2500–5000 mm; at higher altitudes, rainfall reaches 7000 mm, and occasionally 10000 mm (Kagoshima Prefecture 1992). At the coast, the annual mean temperature is about 20℃ (Tagawa 1994); above 1000 m a.s.l., the climate is much cooler, with snow cover in winter.

On Yakushima, intensive logging began in the upland regions for cedar. Logging of conifers increased in the 1950s but decreased in the 1960s owing to tree depletion (Fig. 2). However, with increased demand for wood and pulp products, the logging area shifted to broad-leaved forests at intermediate altitudes. Logging volumes of broad-leaved trees increased significantly from 1963, but decreased after 1973 (Fig. 2) with the reduction in the market price of wood (Japan Federation of Bar Associations 1991) combined with increased awareness of nature conservation (Kamiyaku Town 1984). After the logging of broad-leaved trees, Japanese cedar was widely planted in areas that were not the natural habitat of this species (Fig. 2).

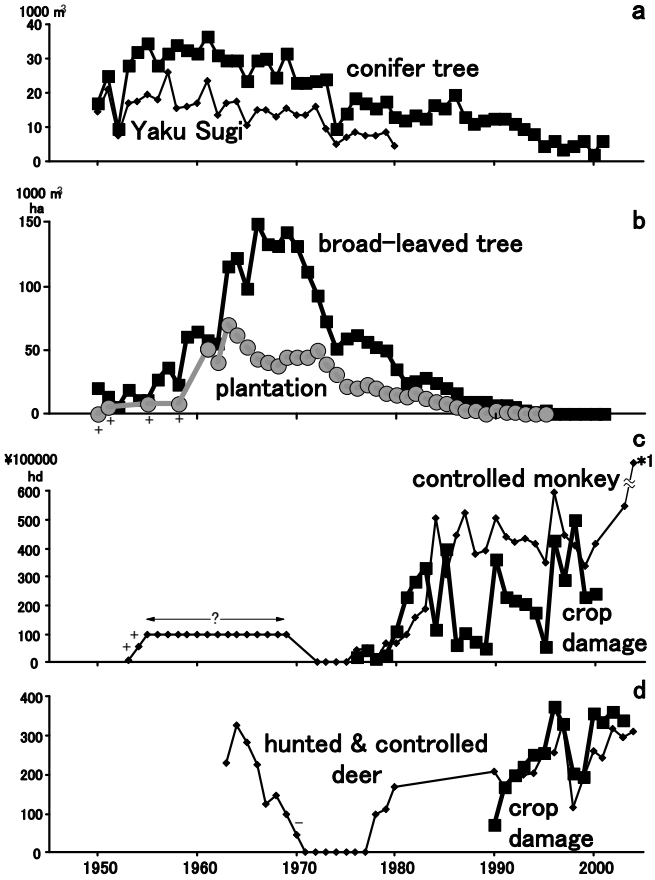

Fig. 2. Annual logging volumes, conifer planting areas, agricultural crop damage by wildlife, and number of hunted animals. Possible underestimated values (+), possible overestimated values (–), and approximate values (?). (a) Logging volume of conifer trees (solid line) (Suwa pers. commun.) and cedar (thin line) (Fujimura 1971; Miura 1984). (b) Logging volume of broad-leaved trees (solid line) (Suwa pers. commun.) and conifer plantation area (gray line) (Kagoshima Prefecture 1992; data of Forest Agency). (c) Amount of crop damage (×\100000, ca. $800) by monkeys (solid line) and number of monkeys culled (thin line) (Azuma 1984; Hirose 1984; Kagoshima Prefecture 1992; Agetsuma 1998). Values of *1 are 833 individuals. Monkeys were captured for experimental use in the 1950s and 1960s. After 1972, all captures were conducted as pest control measures. (d) Amount of crop damage by deer (solid line) and the number of hunted and culled deer (thin line) (Kagoshimaken Shizen Aigo Kyokai 1981; Kagoshima Prefecture 1992; Sueyoshi 1992). Deer hunting was prohibited during 1971–1977. From 1999, deer control has focused in the vicinity of farms.

Land-use changes in lower areas

Below 300 m a.s.l., the inhabitants of Yakushima had deforested the land and cultivated it intensively for traditional practices, such as swidden cultivation, fuelwood, and charcoal (Sprague unpub. data). As a result, the area of "rough land," that is, treeless land, spread extensively in the 1920s (Sprague unpub. data). On Yakushima, monkeys (Agetsuma 1995) and deer (Agetsuma and Agetsuma-Yanagihara 2006) in a natural forest are mainly dependent on the tall trees for their foods; therefore, a “treeless land” may be of little use to them, although deer could utilize herbaceous plants (Takatsuki 1990) and monkeys could feed on the fruit of some shrubs (Hanya 2004). In addition, increased human activity in farming areas would discourage the use of such places by these animals. However, fuel and fertilizer revolution occurred. In addition, because of

the shift in the industrial structure of the island, the area of farmed land and number of farmers decreased significantly between 1950 and 1975 (Fig. 3). Then, some areas of treeless land and farmed areas were converted to orange groves in the 1970s through the promotional efforts of local governments (Agetsuma 1998). Although, most treeless lands were abandoned and subsequently reverted to broad-leaved forests after 1970s (Sprague unpub. data), thereby providing renewed resources for wildlife. Consequently, in lower areas, an overall decrease occurred in treeless lands with a simultaneously increase in broad-leaved forests and orange groves. Production of oranges has increased greatly since 1980 (Fig. 3).

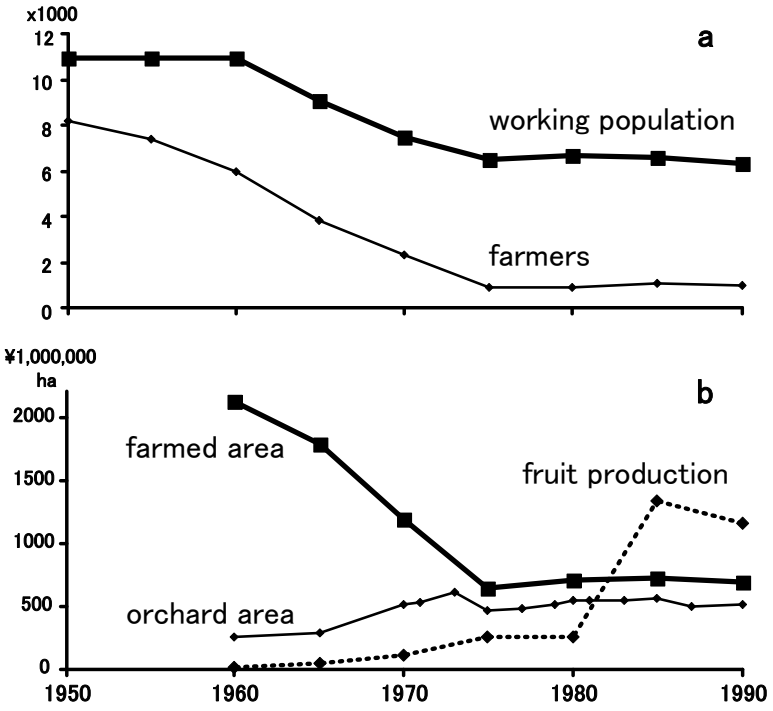

Fig. 3. Working population, farmland area, and fruit production (×\1000000, ca. $8000) in Yakushima. (a) Total working population (solid line) and numbers engaged in agriculture (thin line) (Kagoshima Prefecture 1992). (b) Farmed areas of the five main crop items (solid line), orchards (thin line), and fruit production (broken line) (Kagoshima Prefecture 1992; Agetsuma 1998).

Outbreaks of crop raiding and pest control

Monkeys damage oranges, other fruits, and sweet potatoes (data of Kamiyaku Town). On the island of Yakushima, crop raiding by monkeys was reported before 1950 (Itani 1994), but the amount of damage increased greatly after 1980 (Fig. 2). After 1978, in response to crop raiding, local governments implemented pest control on monkeys. However, between 1978 and 1983, even though the number of controlled monkeys increased, crop damage still increased (Fig. 2) and the high level of damage is continuing, even though 300–600 monkeys have been culled every year since 1984. In spite the fact, many assume that increases in the monkey population have been averted by culling. However, the numbers have not been determined scientifically but have been influenced mainly by voluntary efforts of local hunters and the availability of bounties from local governments. Therefore, it would be purely coincidental if the number of monkeys culled equalled the number required to halt population growth. It is more likely that the population has increased to match the number culled, thereby maintaining a constant population size.

On Yakushima, severe raiding of agricultural crops by deer has been recorded from the 18th century (Kamiyaku Town 1984). However, over the last 60 years, crop raiding by deer greatly increased in the 1990s (Fig. 2). Crops damaged were mainly orange trees by bark stripping (data of Kagoshima Prefecture), sweet potatoes, and rice (Sueyoshi 1992). Deer hunting has been conducted traditionally in Yakushima, and during the 1950s, more than 1000 deer were killed annually (Kamiyaku Town 1984). The number of hunted deer, however, rapidly decreased between 1964 and 1970 (Fig. 2), and ultimately, deer hunting was banned in 1971. It was reintroduced in 1978 as a pest control measure, but damage to crops and forestry seemed not to be widespread during this period (Tagawa 1987). Deer control was implemented over the whole island, and thus deer with no association to crop damage were also controlled. However, from 1999, deer control was limited to around farmland in an effort to target actual raiding deer. After 1980, the number of culled deer remained at 200–300 (Fig. 2). Thus, raiding deer were controlled more intensively than pre-1999, but no reduction in crop damage occurred.

From the empirical data, two common trends in crop raiding by both mammals are recognizable. One is the timing of the rapid increase in crop raiding, which occurred after a delay of approximately 20 years from the logging peak of broad-leaved forests (Fig. 2). The other is the ineffectiveness of pest control in reducing crop damage.

Impact of forest development on mammal ecology

The impact of transforming natural forests to monotonous conifer plantations on the ecology of wildlife includes alteration in diet, habitat use, and other behaviors (Gill et al. 1996). To evaluate the impact, population density is used as an easily measurable index. On Yakushima, the density of monkey groups has tended to decrease with the spread of plantations (Hill et al. 1994) and correspond closely to the food production of forests (Hanya et al. 2004, 2005). Ohsawa et al. (1995) and Agetsuma et al. (2003, unpub. data) surveyed deer density in forests at different degrees of planting. These studies showed that deer densities in heavily planted sites were much lower than those of relative undisturbed sites (Fig. 4). The impact cannot be minimized, even several decades after planting. Deer hunting and cull statistics suggest that the deer population declined soon after intensive logging. Numbers of hunted deer decreased greatly in the 1960s (Fig. 2), which may indicate a population decline. Similar decreases in population densities caused by food depletion due to the establishment of conifer plantations have also been reported in roe deer (*Capreolus capreolus*) (Gill et al. 1996) and Japanese serow (*Capricornis crispus*) (Sone et al. 1999). It is probable that the monkey and deer populations decreased owing to lowered productivity through logging and planting. Subsequently, they gradually recovered, in tandem with renewed production, mainly in naturally regenerating forest stands.

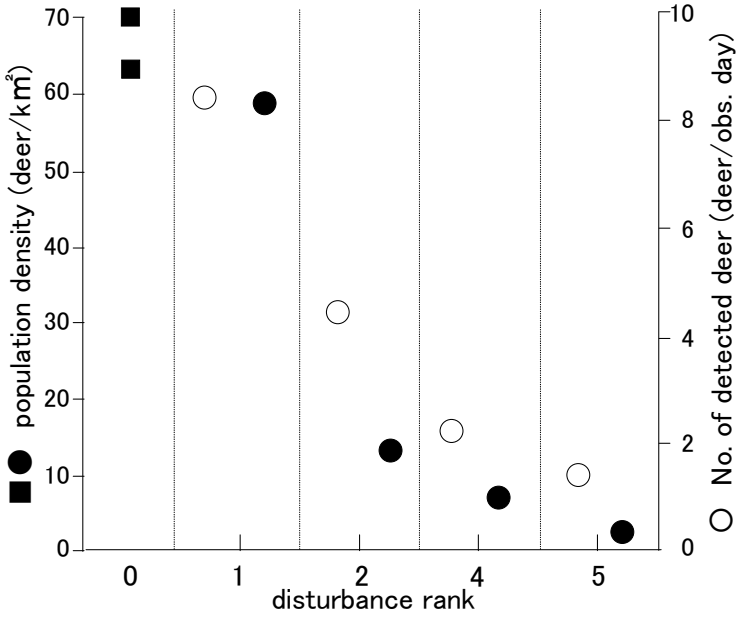

Fig. 4. Relative deer population density at six sites in Yakushima. Solid squares indicate estimated population densities in two lowland natural forests (50–200 m a.s.l.) almost without plantations in 2001 (Agetsuma et al. 2003). Solid circles indicate the estimated densities in 2004 (Agetsuma et al. unpub. data) and open circles denote the number of detected deer per observation day in 1994 (Ohsawa et al. 1995) at four sites, including plantations at intermediate altitudes (300–700 m a.s.l.). Sites with higher disturbance ranks have more areas of younger plantation. Disturbance rankings 1–5 are from Hill et al. (1994).

Relationship between crop raiding and habitat transformation

In Hyogo Prefecture, a positive relationship was found between the occupancy of conifer plantations and crop damage by deer (Sakata et al. 2001). In addition, crop damage by monkeys was greater in regions with 40–50% areal coverage by conifer plantations (Japan Society for Preservation of Birds 1988). These statistics imply some negative influences of plantations regarding the prevalence of crop raiding. On Yakushima, crop raiding increased rapidly with fluctuations in food resources after logging and conifer planting. However, the populations might have been lower than the pre-intensive logging period, which means that a population eruption cannot explain the onset of intensive crop raiding. Crop raiding is possibly influenced by specific ecological and behavioral changes; otherwise, more incidences of raiding would have been previously recorded (i.e., in the1950s) when the animal population was higher and the area of farmland greater than in the 1980s (Fig. 3). Ambiguous or inverse relationships between herbivore densities and damage to crops, forestry, or natural vegetation have been reported (e.g., Oi and Suzuki 2001; Sakata et al. 2001). Ochiai (1996) suggested that damage to plantation trees by serow commenced before the increase in population density. These data suggest that functional responses, such as a shift in ecological strategies, play an important role in crop raiding, rather than simply wildlife density.

The reasons why animals change ecological strategies might be explained as adaptations to fluctuations in habitat. Different ecological strategies has been understood as adaptations to habitat stability and unpredictability (e.g., Begon et al. 1986). Such adaptations would explain interspecific differences of ecology. Similarly, the same species and even individuals within their respective ranges of capability must change their ecology in relation to habitat stability. To confirm the shift in ecological strategies of mammals

due to habitat disturbance, it is necessary to further analyze the history of habitat disturbances in relation to crop raiding.

Changes in landscape structure would facilitate crop raiding. At the intermediate altitudes on Yakushima island, forests have been transformed into low-productivity conifer plantations. In contrast, at lower altitudes, low-productivity treeless terrain has reverted to broad-leaved forest (Sprague unpub data). The natural resources for wildlife have changed inversely from "middle to low altitude" to "low to middle altitude". This shift in landscape structure encourages raiding and makes it difficult to defend crops. The problem is a result of ecological function loss due to landscape modification. Therefore, appropriate landscape management strategies are required to resolve the issue of crop raiding by wildlife.

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